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C. J. Carter

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THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION

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WRIGHT AIR DEVELOPMENT CENTER
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

GOVERNMENT NOTICES

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FOREWORD

The work described in this report was done at the Electron Tube Laboratory of the Department of Electrical Engineering, The Ohio State University, and was directed and approved by E. M. Boone, Research Supervisor, under Air Force Contract No. W33-038-ac-15162, Research and Development Order No. R-111-51, "Wide Range Tuning Klystrons." It was administered under the direction of the Components and Systems Laboratory, Wright Air Development Center, with Mr. Ludwig Mayer acting as project engineer.

Discussions with various members of the Electron Tube Laboratory of The Ohio State University were very useful in the completion of this research.

ABSTRACT

Research was undertaken in May 1951 to develop a high current density electron gun of the line-focus type. Two types have been developed.

One design uses a single potential anode with an elliptical shaped cathode to concentrate the current into a narrow ribbon-like beam which is less than .040 inch wide. The second design uses a two potential gridded anode structure. The current is concentrated by a factor of 10 from the cathode to the narrowest part of the beam, where the current density is 1 ampere/cm^2.

PUBLICATION REVIEW

FOR THE COMMANDING GENERAL:

DANIEL B. WHITE
Colonel, USAF
Chief, Weapons Components Division

LINE FOCUS GUNS

In the field of micro-wave electronics a wide variety of specialized electron guns are used. Among these there is a group commonly referred to as line focus guns. These are essentially two dimensional structures with no variations in the third dimension except at the end of the structure. It is with the design of guns of this type that this paper is concerned.

A description of the beam produced by an electron gun will serve to describe the performance of the gun. The current and the shape of the beam edges are two important facts concerning a beam. Sometimes it is also important to know the current distribution but more often a knowledge of the total current is sufficient.

It is often necessary to focus a beam through a long narrow tunnel such as the one whose cross-section is shown in Figure 1. Electrons from a line focus source below the figure are caused to converge on the opening to the tunnel which has a breadth t and a length ℓ. The length of the gun structure along the axis perpendicular to the page in Figure 1 is unimportant since there is assumed to be no variation in this direction. The current will be measured per unit length along this axis. The beam is converging as it enters the tunnel. Mutual space charge repulsion causes the beam to pass through a minimum and then start to diverge again. There is a maximum current that can be focused through such a tunnel at a given voltage. At higher current the space charge spreading of the beam will cause part of the current to be intercepted on the tunnel walls.

This maximum current can be calculated for a beam in which the current density is uniform. The calculation is an approximation which is good only when $\ell \gg t$. According to Beck(1) the maximum current is given by $I_{max} = 83.3 \times 10^{-4}\ t/\ell^2\ V_o^{3/2}$ amperes/meter where V_o is the beam voltage; t and ℓ are in meters.

A calculation for a typical tunnel will show that this maximum current is higher than can be obtained from the customary line focus gun. Consider a tunnel with t = 1mm = 0.01 meters, ℓ = 1 cm = 0.1 meter and V_o = 100 volts.

Two different types of line focus gun were built at this laboratory. The first was a single potential gun without grids, the second was a two potential gun with grids. The first is a very simple gun to build but has a relatively low perveance. The second is more complicated and gives relatively high currents. By varying the first anode potential it is possible to control the current independently of the second or final anode potential.

A commonly used method of gun design is the one proposed by J. R. Pierce(2), which uses a section of rectilinear flow of space charge limited current. In the case of a line focus gun the current would flow radially inward from a section of a cylindrical cathode toward a cylindrical anode of smaller radius. To use the beam a slot is cut in the anode

cylinder for the beam to pass through. The slot, however, distorts the electric field in the region of the anode causing defocusing of the beam. This effect becomes more serious as one attempts to increase the gun perveance by increasing the anode radius relative to the cathode radius.

The effect of the hole in the anode can be compensated for by bending in the edges of the cathode to form an elliptical surface which has its maximum curvature at the edge. The determination of all design dimensions must be done experimentally. However, one small bit of information is available before starting. It is known that the beam forming electrode must make an angle of 67.5° with the beam edge near the cathode.

Three independent variables are needed to describe the cathode shape. The length of the major axis of the ellipse, the axial ratio of the ellipse and the length across the top of the cathode are the most convenient variables.

It is convenient for experimental purposes to hold the length across the top of the cathode constant. This can be done without reducing the generality of the results since it is always possible to scale the resulting gun to any size within limits.

The shape of the anode and the beam forming electrode must be determined experimentally. Since there are an infinite number of variations of shapes it is necessary to use a general approach to the problem.

In theory, if one had complete control of the electric fields in a gun structure it should be possible to produce any beam shape and current distribution desired. However, this would often involve cases in which electrical field sources or sinks must be placed in the region of current flow. These sources or sinks must be metallic electrodes and will collect current. This is not always practical.

Fortunately many practical beam shapes can be produced with electric fields whose sources and sinks other than space charge are external to the region of current flow. It is convenient, therefore, for experimental purposes to have an array of electrodes situated just outside the expected region of current flow. By varying the potentials on these electrodes independently it is possible to focus the beam into a wide variety of shapes. A relatively small number of electrodes will give a very wide range of control over the beam.

The number of control electrodes is a compromise between the degree of control desired on the one hand and the difficulty in building and manipulation of the other hand. Three sets of electrodes as shown in Figure 2 were used in all of the experiments. This arrangement was found to be very satisfactory.

A series of cathodes of various axial ratios and major axes were tried with this electrode arrangement. Each cathode had a corresponding beam forming electrode cut to make an angle of 67.5° with the beam edge. The potentials on the three electrodes were varied to obtain the narrow-

est beam width possible with an angle of divergence less than 40° included angle. The beam shape was observed on a target covered with soot. All experiments were performed on a demountable pump station, where changes could be made rapidly.

After selecting the best cathode and determining the relative electrode potentials which produced the best beam, a model of the entire electrode arrangement was set up in a plotting tank. A field plot was made using the same relative potentials as were used on the gun. From a study of this field plot, trial anode and beam forming electrode shapes were determined. A model of this trial gun design was placed in the plotting tank where it was possible to determine what small changes needed to be made so that the fields would correspond to those obtained with the original electrode arrangement.

For ease in manufacture the final electrode shapes should be as simple as possible. A little experimenting in the plotting tank will generally show which features are important in shaping the field and which are not.

The final electrode arrangement is shown in Figure 3. The cathode ellipse has an axial ratio of 1.3 and a major axis of 0.608 inch. This gun has a perveance of approximately 2×10^{-6} per cm of axial length. Because of the distortion of the field at the ends of the gun due to improper termination of the structure, about 10% of the current is intercepted in a gun which is 4 cm long. The included angle between the edges of the beam is approximately 40°. The current density is increased by a factor of approximately 14 from the cathode surface to the narrowest portion of the beam. This concentration ratio is achieved with a simple electrode arrangement. Much higher ratios can be obtained with a corresponding increase in the complexity of the electrodes, but since the above performance met the specifications the added complexity was unwarrented.

In order to obtain a high perveance line focus gun it is necessary to use gridded anode. Figure 4 shows a close spaced high perveance gun. Two anodes are used so that the current can be controlled independently of the final anode voltage. The first anode which operates at a relatively low voltage intercepts some current. The intercepted current is reduced to a minimum by ribbing the cathode so as to focus the current between the anode sections. A plot of the current division is shown in Figure 5. The voltage versus beam current characteristics are shown in Figure 6.

This anode structure will cause both axial components of velocity and axial variations of current density. These effects, however, are not large and for most applications they will cause no trouble. No axial variation in current density can be noticed when the beam is observed on a soot covered target.

In principle the electrons move in a radial direction and should focus on the axis. Actually the main portion of the beam is 0.050 to 0.055 inch wide with the minimum slightly above the axis. Except for very low values of the anode voltage ratio the width and position of the

minimum does not change. This indicates that the spreading is not caused by space charge, but is a result of inaccuracies in the construction, initial velocities and such things. A small amount of eccentricity could cause considerable spreading. There is also some fringing at the cathode edge, since no beam forming electrode is used. This gun structure must be accurately built to give good results. Steel is used for the small grids. Further, a copper grid would tend to warp when heated.

The maximum current shown in the graph of Figure 6 was measured with only radiation cooling of the second anode. With water cooling it should be possible to go somewhat higher. However, the average cathode current density is 100 ma/cm^2 for a total current of 450 ma. Since the cathode would soon be operating under temperature limited conditions if the current is increased. For this reason this gun should be scaled to smaller sizes only when it is to work at proportionally lower voltages.

The current density is increased by a factor of 10 from the cathode to the narrowest portion of the beam, giving a beam density of 1 ampere/cm^2 for a total gun current of 450 ma.

In conclusion it should be pointed out that when a low perveance line-focus gun is needed, the Pierce design is very satisfactory. However, for higher perveances it is necessary either to correct for the effect of the anode aperture, or to use a gridded anode design. The simplest design which will meet the specifications should always be used.

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(1) A. H. W. Beck. Velocity-Modulation Thermionic Tubes. Page 75.

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(2) J. R. Pierce. Theory and Design of Electron Beams. Chapter X.

ELECTROSTATIC FOCUSING

IN A RECTANGULAR TUNNEL

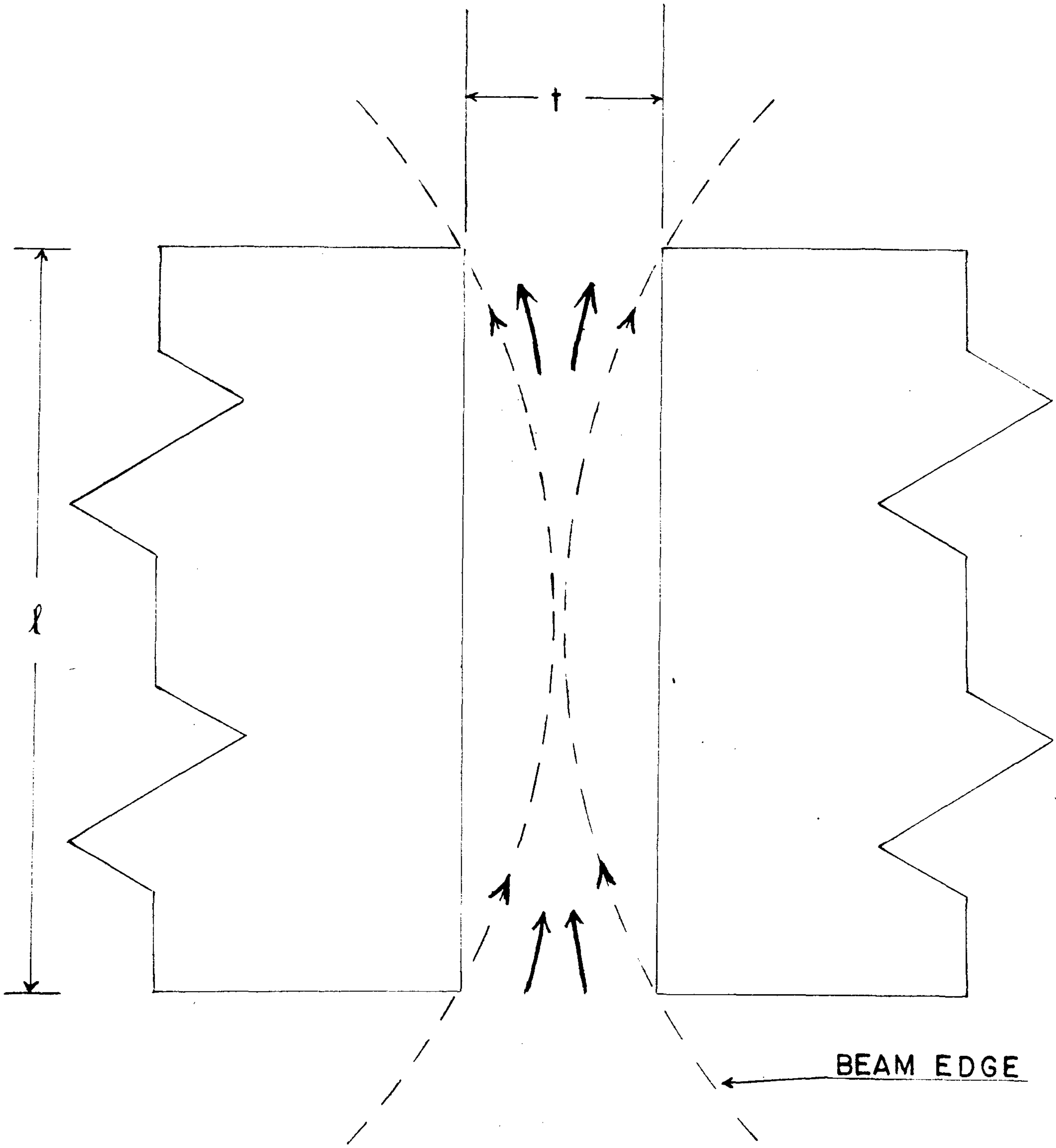


FIG. 1

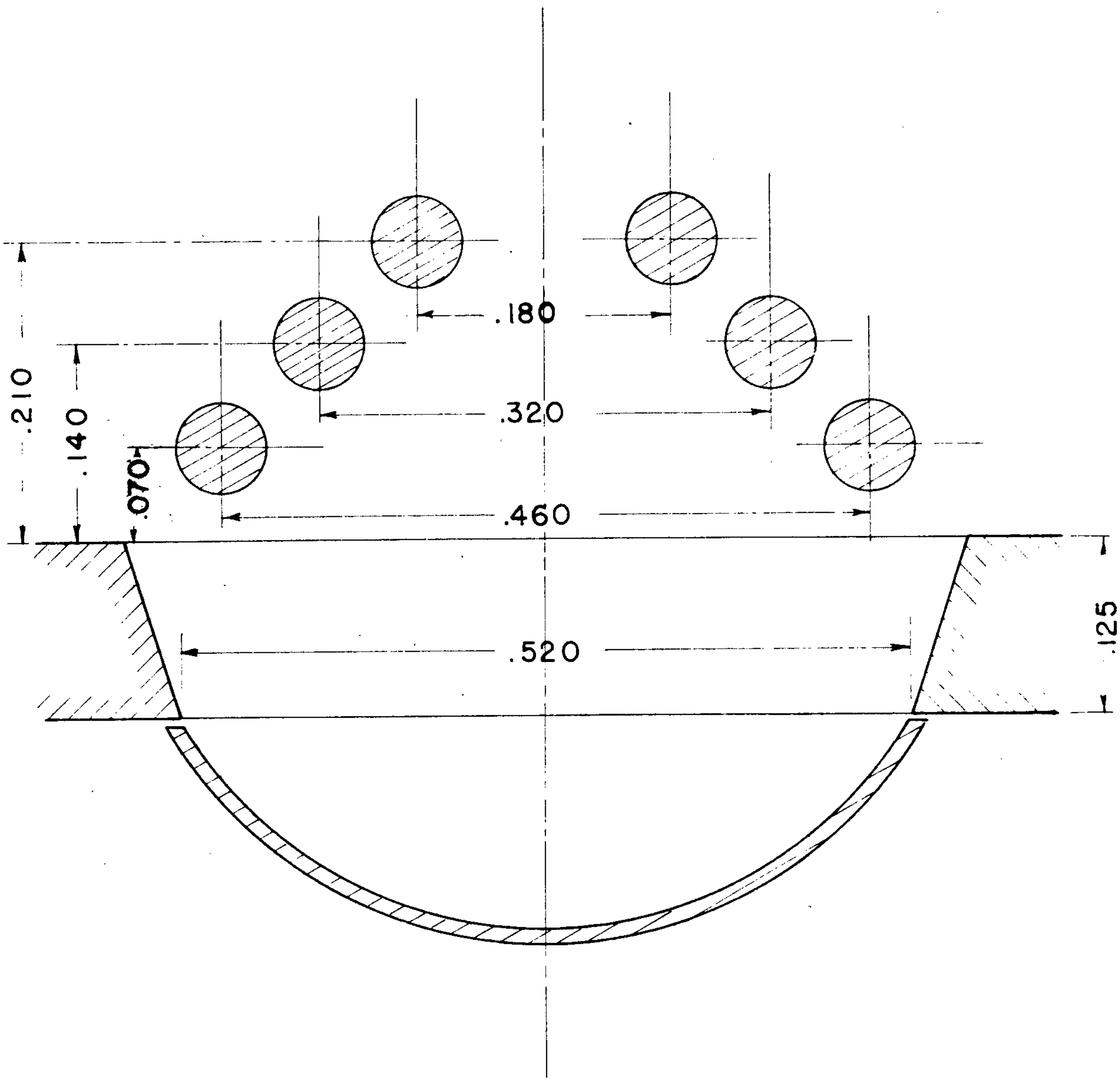
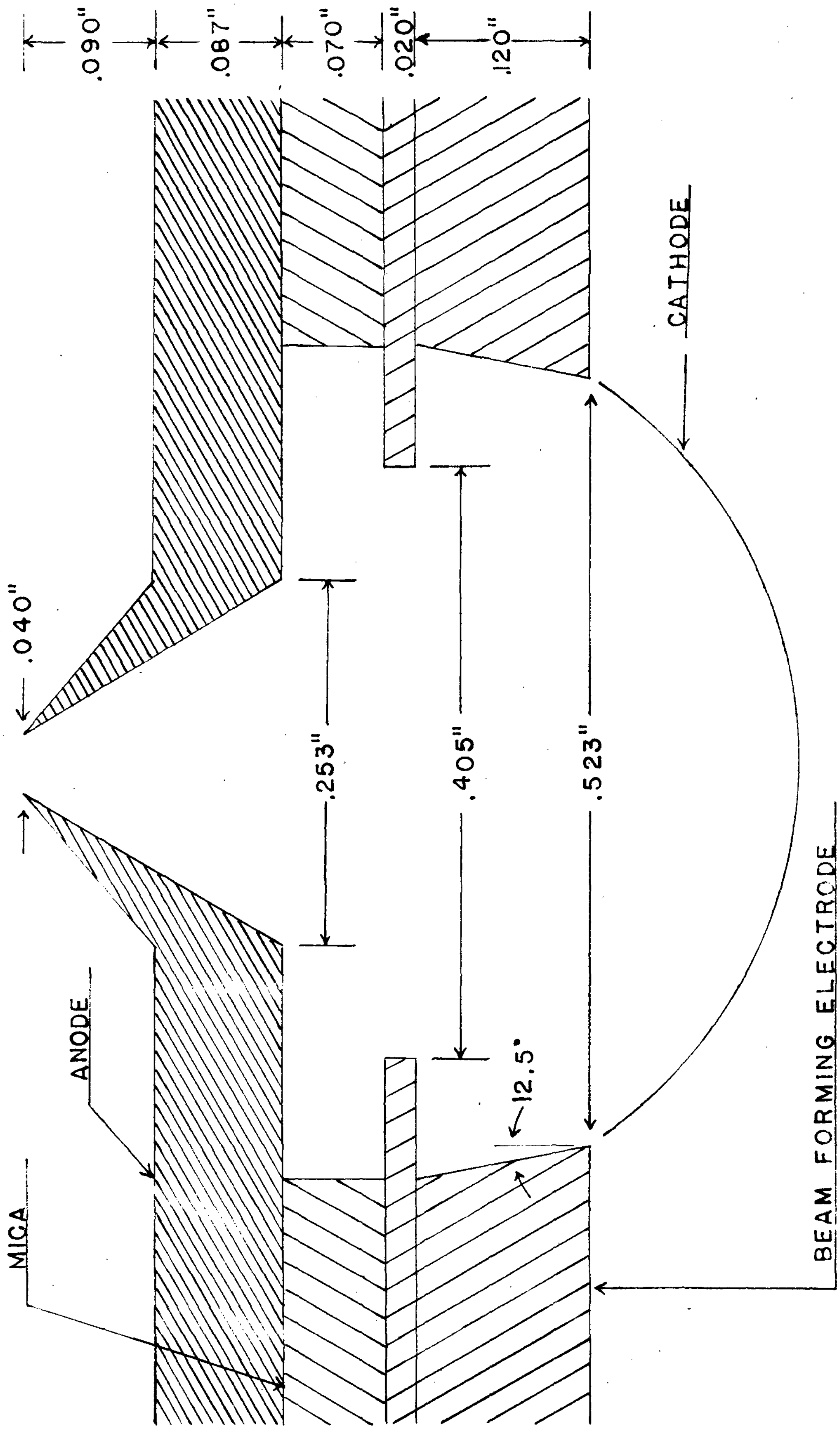


FIG. 2
LINE FOCUS GUN



FINAL GUN DESIGN

FIG. 3

2 ANODE
LINE FOCUS
GUN TESTER

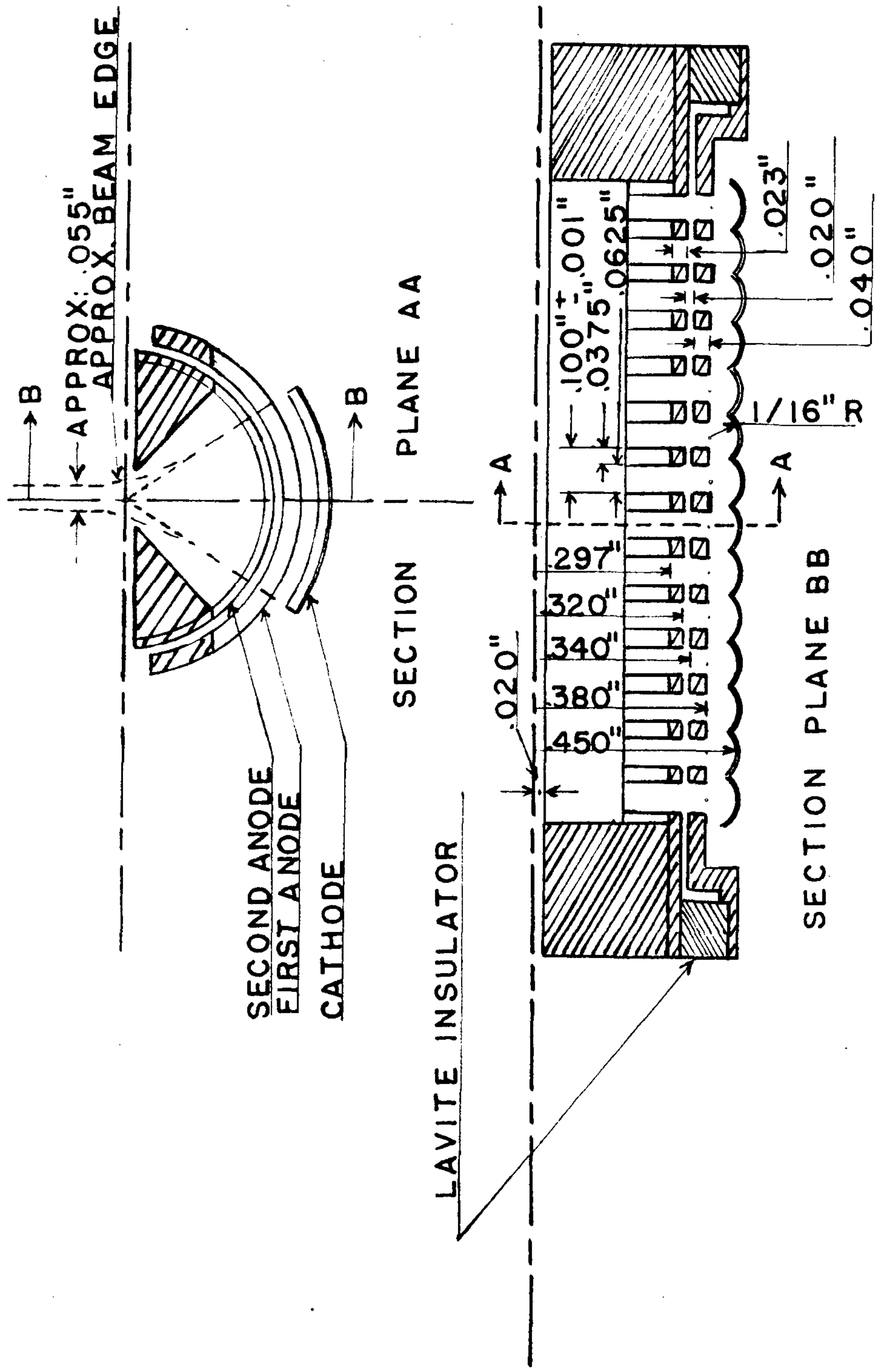


FIG. 4

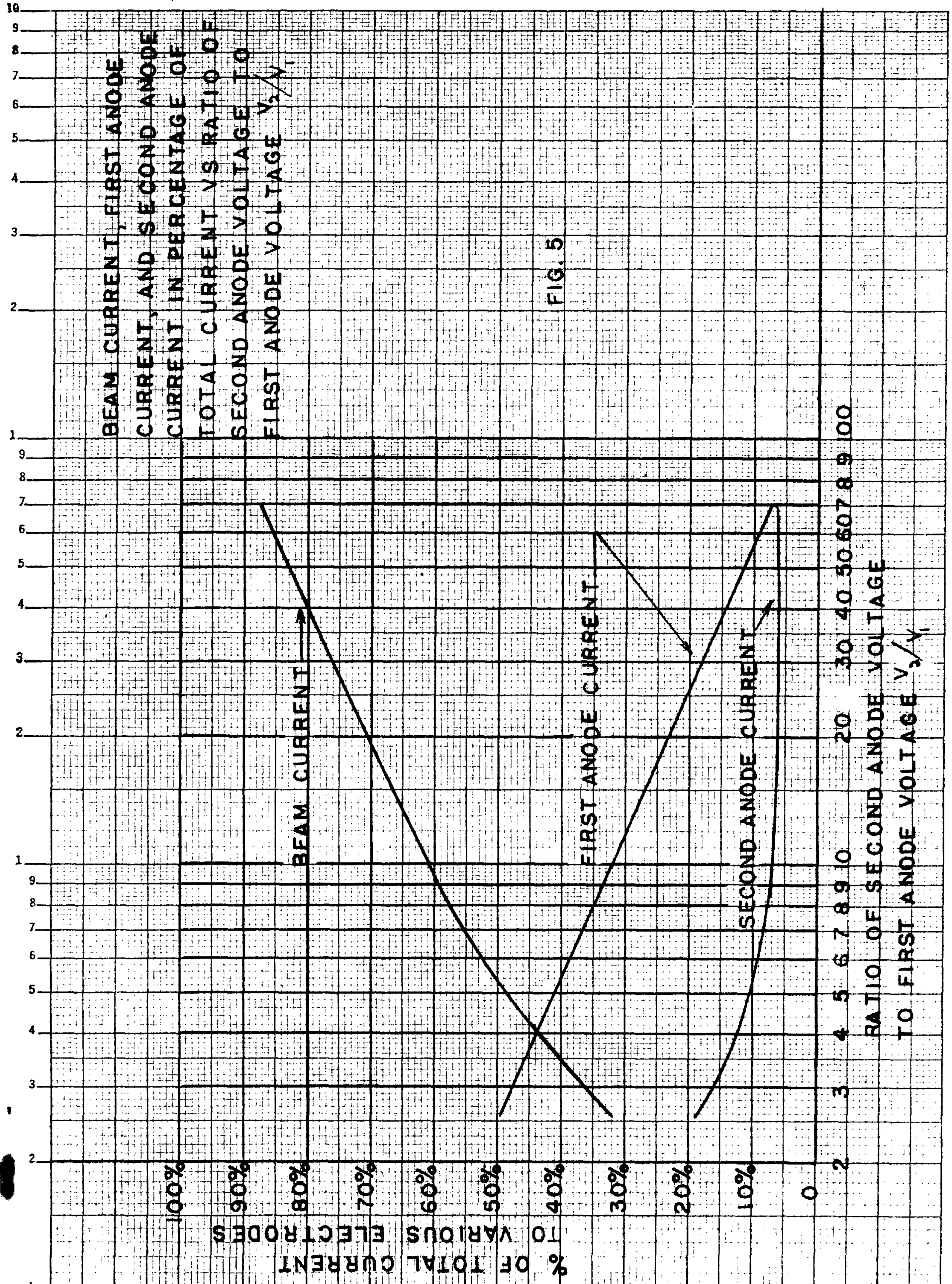
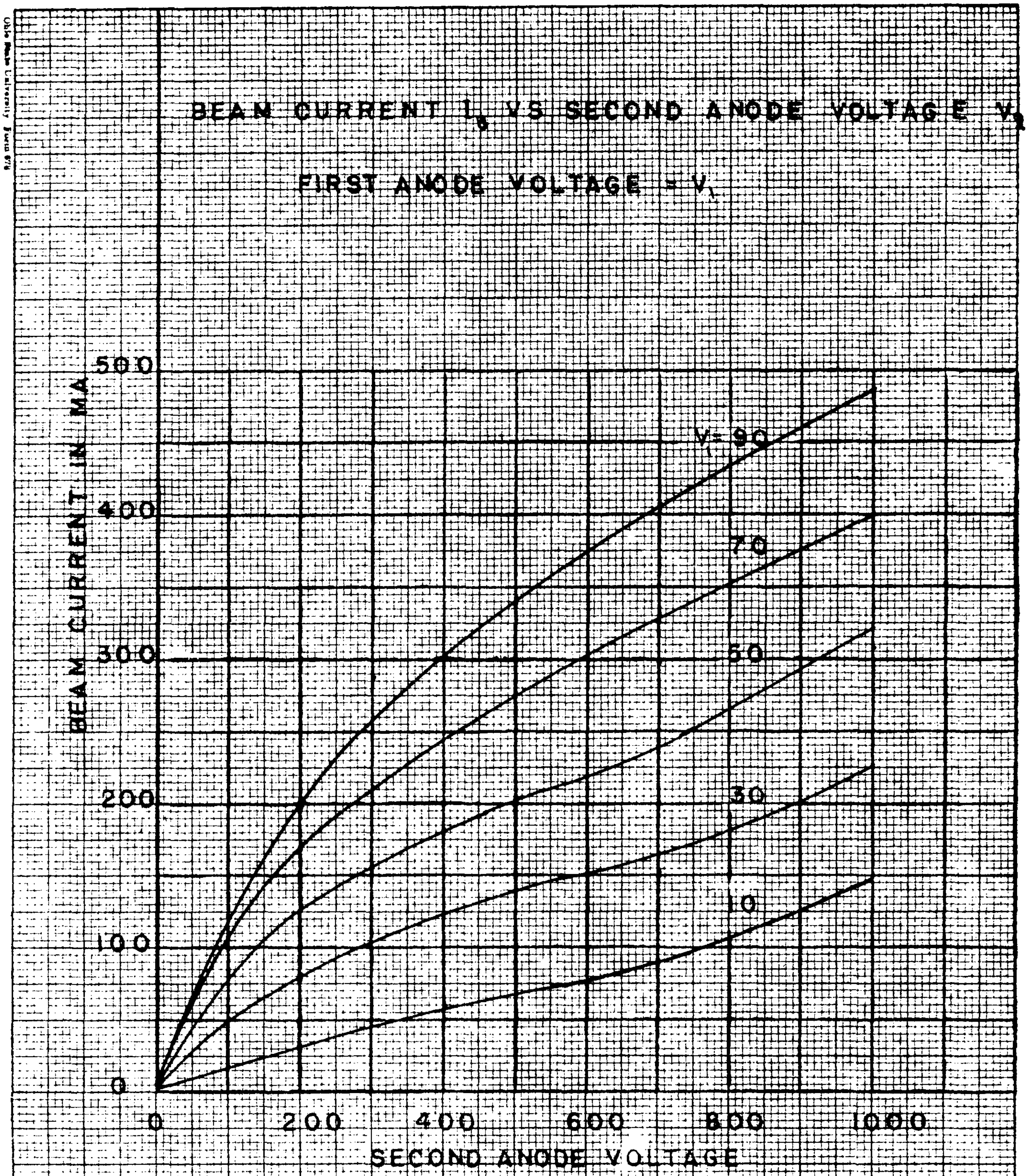

BEAM CURRENT, FIRST ANODE CURRENT, AND SECOND ANODE CURRENT IN PERCENTAGE OF TOTAL CURRENT VS RATIO OF SECOND ANODE VOLTAGE TO FIRST ANODE VOLTAGE V_2/V_1
BEAM CURRENT
FIRST ANODE CURRENT
SECOND ANODE CURRENT
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0
% OF TOTAL CURRENT TO VARIOUS ELECTRODES
2 3 4 5 6 7 8 9 10 20 30 40 50 60 70 80 90 100
RATIO OF SECOND ANODE VOLTAGE TO FIRST ANODE VOLTAGE V_2/V_1

FIG. 5



BEAM CURRENT I_b VS SECOND ANODE VOLTAGE V_2
FIRST ANODE VOLTAGE = V_1
BEAM CURRENT IN MA
SECOND ANODE VOLTAGE
V_1 = 90
70
50
30
10
0
100
200
300
400
500
0
200
400
600
800
1000

FIG. 6